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A STUDY OF DISPLAY INTEGRATION FOR HYPERSONIC RESEARCH VEHICLES

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FOREWORD

This is the first of two technical reports pertaining to the work performed by Norden under NASA contract NASW-675.

It covers the period from May 16, 1963 to August 16, 1963. A final report will be issued on completion of the next quarterly reporting period, November 16, 1963.

This report presents a study program which investigates methods of display integration for the X-15 hypersonic research vehicle. The study program was conducted under the technical guidance of the Display and Guidance Section, Flight Research Center, Edwards, California.

The material covered represents a compilation of existing data concerning the X-15 mission profile and corresponding display requirements. Only introductory information is included concerning specific display applications, since this area will be investigated during the second half of the program.

ABSTRACT

Contact analog techniques are being investigated as a means of display integration for the X-15 hypersonic research vehicle. The basic contact analog display presents flight information in the form of a synthetic television picture corresponding to the real-world view from the cockpit.

Results of preliminary studies of pilot control tasks and flight profiles for the X-15 are included as the basis for development of the optimum display format. Important flight parameters are analyzed with respect to total range of variation and rates of change for display design considerations.

A description of the present X-15 instrument panel is included showing locations and configurations of cockpit displays. Technical characteristics of the inertial flight data system and attitude indicator are given.

Basic requirements for an integrated display for this type of mission include the following.

- Wide dynamic range with good sensitivity
- Capability of displaying command information
- High accuracy
- Flexibility of operation

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1. INTRODUCTION

The X-15 occupies a unique role in today's space research program since it is the only operational aircraft capable of bridging the gap between high-altitude aerodynamic flight and space flight. It is, therefore, apparent that an extreme variation of dynamic conditions exists during such flights, which requires the pilot to perform an unusually wide range of control tasks. The problem of displaying flight information to the pilot is, therefore, complex.

The immediate outcome of this investigation will be a detailed set of recommendations for an advanced type of integrated display based on a thorough analysis of the display problems involved. A follow-on program will be described which concerns construction of feasibility models for evaluation in simulator facilities and research vehicles.

The results of the study will be compiled in the form of a final report to be issued at the end of the program.

2. RESULTS OF STUDY

2.1 The Present X-15 Program

The three X-15 research vehicles have been operational for more than seven years. During this time, the areas of study envisioned in the original program have been essentially completed. Recently, a substantial follow-on program has been instituted which utilizes the X-15 as a versatile hypersonic cruise-vehicle test platform for numerous space and near-space experimentation programs. These experiments will be carried on in the fields shown in Table 2-1.*

The present configuration of X-15 research vehicles 1 and 3 is shown in Figure 2-1. Minor modifications were made in these vehicles to accommodate some of the experiments previously mentioned. Vehicle No. 2 is being rebuilt to extend its performance range for operation to Mach 10 and altitudes to 400,000 feet. Present vehicle characteristics and performance capabilities are listed in Appendix A.

The investigation of integrated displays forms a large part of the current experimentation program, both as a study in itself and ultimately as a means of providing improved control of this and other aircraft for space research. The need for display integration in the X-15 and other manned space-research vehicles resulted from increasing demands imposed on the pilot to make rapid decisions based on information obtained from many sources. Present display methods require the pilot to scan several displays to gather the necessary data for such decisions. The objective of display integration is to present as many variables as possible in a format that can be assimilated quickly in a single viewing.

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* Refer to Appendix C, reference a.

Table 2-1. Current X-15 Experimentation Program

NUMBER	EXPERIMENT	MISSION
1	Ultraviolet stellar photography	High altitude
2	Ultraviolet exhaust plume characteristics	Above 25 miles
3	Horizon definition	Above 40 miles
4	Optical-degradation measurements	Varied
5	Detachable high-temperature leading edges	High heating
6	Infrared exhaust signature	100,000 feet to 130,000 feet
7	High-temperature windows	Varied
8	Atmospheric-density measurements	Above 125,000 feet
9	Micrometeorite collection	Above 150,000 feet
10	Advanced integrated-data systems and energy management	Varied
11	Vapor-cycle cooling	Long duration zero g

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Figure 2-1. X-15 Research Vehicle

2.2 Flight Profiles

As shown in Table 2-1, the X-15 vehicles perform a wide range of missions, each flight with its own particular goals and flight profile. A typical range of altitude and speed profiles is shown in Figure 2-2.

Altitude profiles involve high-angle flight paths during the boost phase followed by a period of ballistic (zero g) flight.* Altitude flights are of the longest duration and require the greatest degree of accuracy of control. The accuracy required is indicated by the fact that one degree of pitch error during boost results in a peak altitude error of approximately 7000 feet. Entry into the atmosphere from such flights becomes critical because of the high accelerations and aircraft instabilities involved.

Speed profiles generally require a relatively shallow flight path during boost followed by a period of ballistic or level flight. Peak altitudes attained are roughly one-half to one-third of those achieved in altitude build-up missions. Because of the relatively low altitudes and high velocities involved, high levels of dynamic pressure with resultant aerodynamic heating are experienced in speed flights.

For the purpose of analysis, each flight profile can be divided into the following four major phases:

a. Boost
b. Ballistic
c. Entry
d. Terminal

The boost phase can be further divided into rotation and climb subphases. This study will treat the display requirements for each phase separately.

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* Refer to Appendix C, reference b.

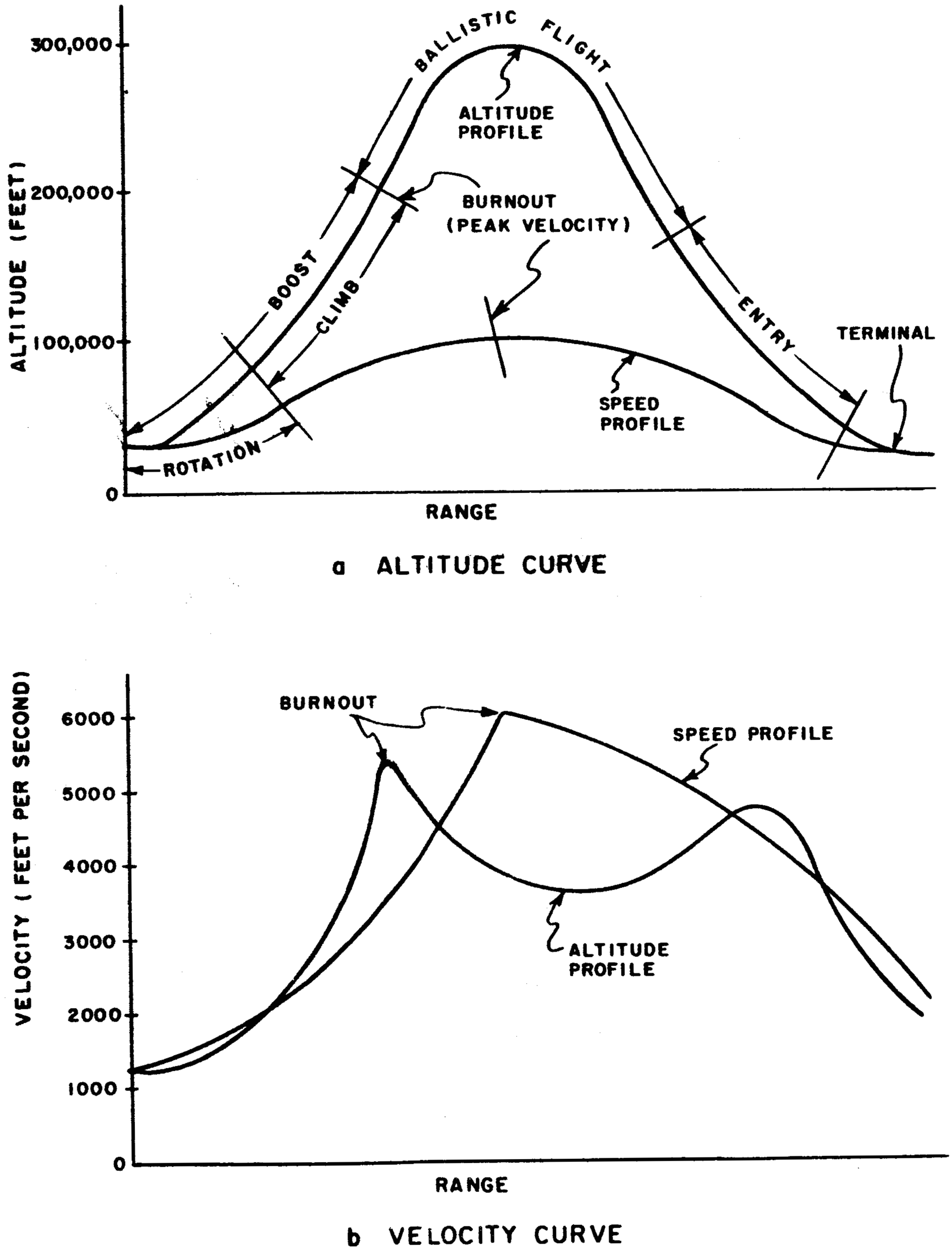

Figure 2-2. X-15 Flight Profiles

2.3 Pilot Tasks

A compilation of representative pilot tasks for many types of missions appears in Table 2-2. This table lists only tasks pertaining to accomplishment of a particular mission. These must be performed in addition to the normal, or recurring tasks required to operate the aircraft in all other respects, such as maintaining trim, attitude, heading, and voice communications.

Specific information for each mission is transmitted to the pilots in the form of flight request sheets, giving a breakdown of all flight control requirements on a second-by-second basis from the time of launch. Each entry gives the altitude, velocity, angle of attack, dynamic pressure, and special pilot instructions corresponding to a particular time. Emergency and abort information is also included.

The present method of operation requires that the pilot memorize this information prior to each flight. A basic requirement of an integrated display would be the capability of presenting this type of command information during flight.

2.4 Pilot Task - Display Parameter Analysis

Information is being obtained from X-15 pilots concerning the display information required for a selected list of pilot tasks. Pilots are being asked to classify flight parameters for each task according to relative importance in accomplishing the task. Parameters are being ranked using the terms "primary", "secondary", and "monitor" in order of importance. These data will form the basis for selection of variables to be incorporated in the integrated displays. Mode switching will be investigated as a means of reducing the number of variables displayed at any given time. This requires development of a display system with inherent flexibility of operation.

Table 2-2. Representative Pilot Tasks

FLIGHT PHASE	TASK
Launch	a. Drop b. Ignite engine c. Hold 2 degree right aileron
Rotation	a. Maintain constant heading b. Maintain constant 2 g until given pitch angle
Climb	a. Maintain constant pitch angle; heading b. Reduce thrust at given time c. Shutdown engine at given time; velocity d. Pushover to zero g at given time; speed; altitude; or rate-of-climb e. Monitor maximum velocity
Ballistic	a. Maintain zero g b. Maintain constant vertical speed c. Extend speed brakes d. Maintain level flight e. Maintain maximum 8 degree pitch and roll error f. Roll in and release given bank angle g. Fly proportional to bank angle; roll rate h. Monitor peak altitude
Entry	a. Establish given angle of attack b. Perform airleron deflection pulse c. Perform rudder deflection pulse d. Monitor dynamic pressure e. Monitor angle of attack

Table 2-2. Representative Pilot Tasks (Continued)

FLIGHT PHASE	TASK
Entry (cont)	f. Retract speed brakes g. Hold constant g pullout h. Monitor vertical speed i. Make level flight recovery
Terminal	a. At key checkpoints: Establish proper altitude, airspeed, ground position, turn rate, and rate-of-descent b. Jettison vertical fin at given altitude c. Before Flareout: Establish proper airspeed, height above runway, and sink-rate d. Lower flaps; gear e. Touchdown at given point on runway

Important considerations in the design of integrated flight displays are the ranges of variation encountered in the flight parameters in actual operation, and the maximum rates of change of these parameters. Table 2-3 lists these characteristics for the X-15 flight parameters, indicating the sensors which furnish the input information.*

It is apparent that the rates associated with attitude parameters are of such magnitude as to require display devices capable of following large changes with minimum time lag and overshoot. The extremely wide ranges of variation associated with altitude and speed parameters require the additional capabilities of large dynamic range with high sensitivity. A combined display capable of handling both groups of parameters must, therefore, possess the opposing characteristics of fast response, large dynamic range, and high sensitivity with readability.

2.5 Flight Sensors

Two primary sensors provide the input data for the flight instruments. These include:

a. Inertial Flight Data System (stable platform)

b. Hypersonic Flow Direction Sensor (ball nose)

They are discussed in detail in the following paragraphs.

2.5.1 Inertial Flight Data System

Input information for displaying vehicle velocity, height, rate-of-climb, and attitude is provided by the inertial flight data system.** A functional diagram of this system is shown in Figure 2-3. The two major system components are the stabilizer, which contains the sensory elements, and the computer, which processes data from the sensors to furnish the necessary outputs.

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* Refer to Appendix C, reference a.

**Refer to Appendix C, references e and f.

Table 2-3. Characteristics of X-15 Flight Parameters

PARAMETER	TYPICAL RANGE OF VARIATION	MAXIMUM RATE OF CHANGE	SENSOR
Barometric Altitude	0 - 60,000 feet	------------	Ball Nose
Inertial Height	4,500 - 500,000 feet	±4000 fps	Platform
Inertial Speed	700 - 7,000 fps	120 f/sec^2	Platform
Airspeed	0 - 450 knots	------------	Ball Nose
Mach meter	Mach .2 to Mach 2.5	------------	Ball Nose
Vertical Speed	± 4000 fps	------------	Platform
Dynamic Pressure	0 to 2000 psf	75 psf/sec	Ball Nose (total pressure)
Angle of Attack	-10° to $+35^{\circ}$	12 deg/sec	Ball Nose
Angle of Sideslip	$\pm 10^{\circ}$	10 deg/sec	Ball Nose
Pitch	$\pm 60^{\circ}$	12 deg/sec	Platform
Heading	360°	10 deg/sec	Platform
Roll	$\pm 120^{\circ}$	30 deg/sec	Platform
Time	0 to 800 sec	------------	Stop Watch
Acceleration			
Longitudinal	-2 g to +4 g	------------	Accelerometer
Lateral	-1 g to +1 g	------------	Accelerometer
Normal	0 g to +6 g	------------	Accelerometer
Ground Track Distance	325 mi	1 mi/sec	Platform

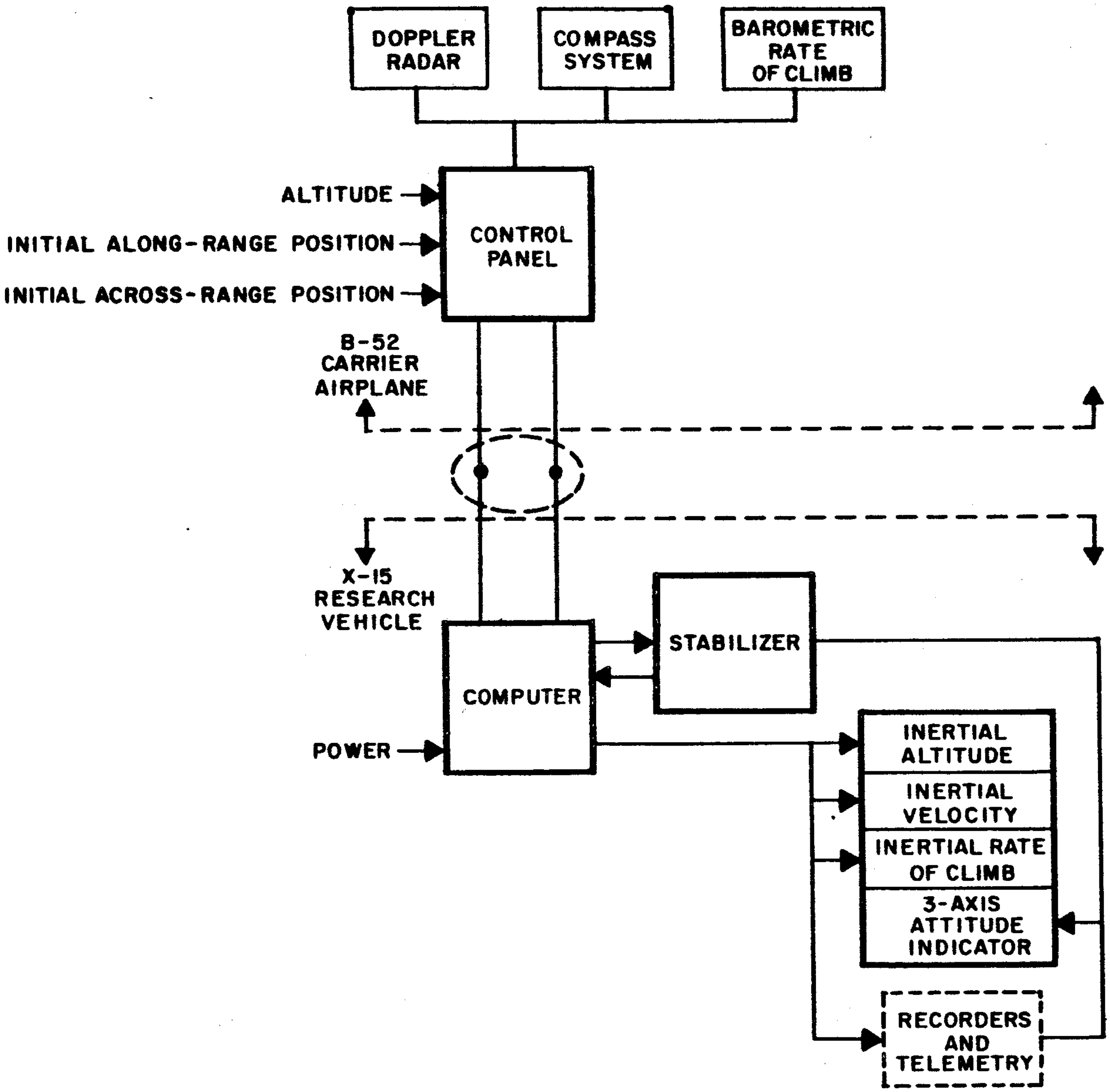

Figure 2-3. Inertial Flight Data System, Functional Diagram

Initial conditions necessary for proper alignment of the system prior to launch are provided from a control panel in the B-52 mother ship. Initial velocity is determined by means of Doppler radar and is transformed into along-range and across-range components in the control panel. Rate-of-climb information is introduced from a barometric rate-of-climb sensor, and heading is derived from an N-1 compass system. Initial position and altitude are inserted manually.

A block diagram of the on-board inertial system is shown in Figure 2-4. The stabilizer, or stable platform, is maintained normal to the local gravity vertical under all possible conditions of attitude and acceleration by means of three integrating gyros on a mount having four separate gimbals. The sequence of rotation from the case inwards is roll, pitch, inner roll, and azimuth. The pitch, inner roll, and azimuth axes are maintained mutually perpendicular, while the outer-roll axis is gimbaled with respect to the aircraft fore-aft axis. This redundant roll gimbal is necessary to allow unlimited maneuverability about any axis without the possibility of gimbal lock or loss of verticality. The servo amplifiers for each axis are mounted directly on the gimbal being driven.

Three linear accelerometers are mounted on the platform and act as the primary sensing elements for velocity and position information. These have an accuracy in the order of 10^{-4} g.

The computer processes the accelerometer outputs to derive the variables to be displayed in the proper form. As a necessary part of this function, it also furnishes earth-rate and acceleration correction signals to precess the gyros. Earth-rate corrections are necessitated by the requirement for displaying velocity with respect to the earth's surface, since the platform senses only velocity with respect to inertial space. Acceleration

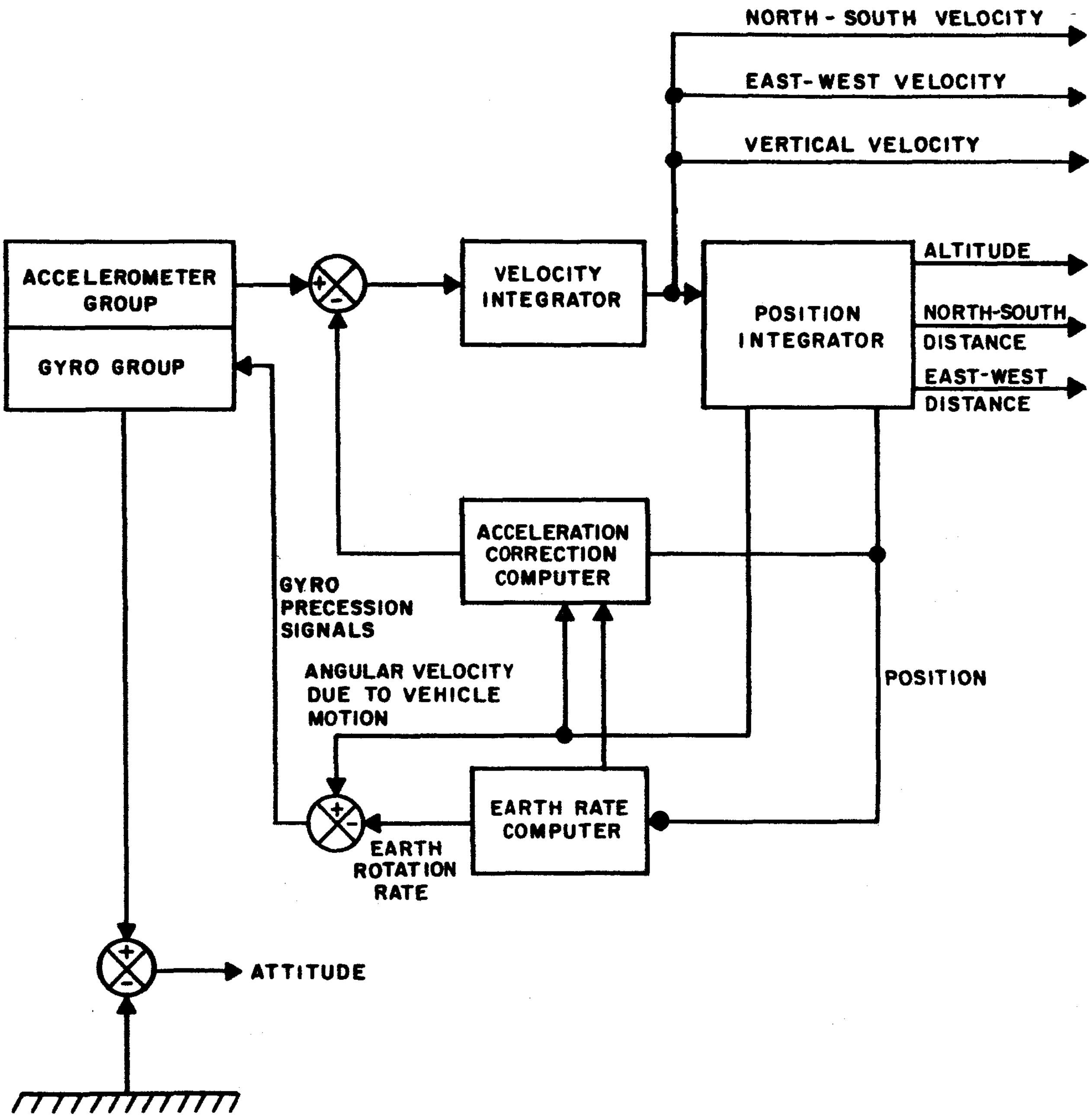

Figure 2-4. Inertial System, Block Diagram

corrections compensate for errors introduced by Coriolis and Centripetal accelerations, as well as errors resulting from variations in mass attraction with altitude due to gravity gradient.

The computer outputs are furnished to the displays both as synchro signals and as potentiometer resistances. These interface data are given in Appendix B.

2.5.2 Accuracy of Inertial Data

The accuracy characteristics of the inertial flight data system are shown in Figure 2-5.* Velocity information is sufficiently accurate to be used for flight control over most of the flight. However, altitude error increases with time until, near the end of the flight, errors result of more than ±10,000 feet. This precludes use of inertial height information over all but the initial phases of flight. For this reason, altitude cues from ground radar data must be furnished to the pilot by voice communications in later flight phases.

Attitude information is sufficiently accurate, throughout the entire flight, since it involves no integrations from platform data.

2.5.3 Hypersonic Flow Direction Sensor

The hypersonic flow direction sensor, Figure 2-6, provides inputs for the display of the following parameters:

a. Angle of attack
b. Yaw angle
c. Airspeed
d. Dynamic pressure

Technical data concerning this sensor will be contained in the final report.

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* Refer to Appendix C, reference f.

CHARACTERISTICS OF INERTIAL FLIGHT DATA SYSTEM

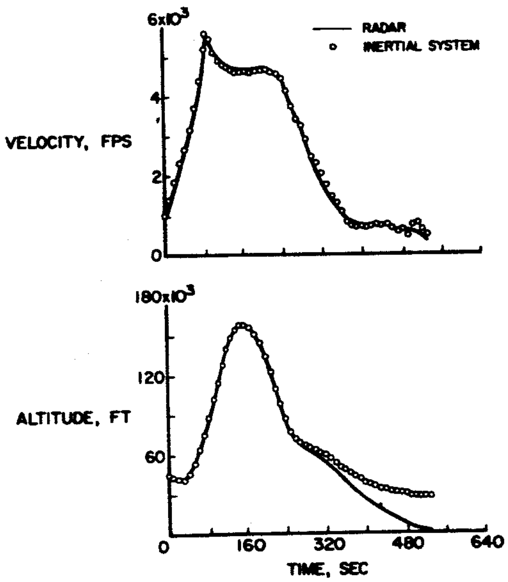

Figure 2-5. Inertial Flight Data System Accuracy

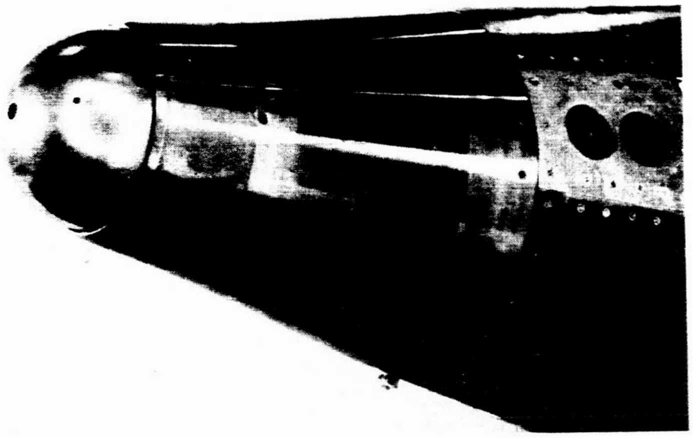

Figure 2-6. Hypersonic Flow Direction Sensor (Ball Nose)

2.6 Present Cockpit Displays

Figure 2-7 shows the layout of the cockpit instruments used in a recent series of flights. Panel configuration changes to test new indicators and indicator arrangements; therefore, little can be discussed about a standard instrument panel. However, the flight instruments shown in Figure 2-7 are typical of those presently in use and include the following:

a. Airspeed indicator
b. Pressure altimeter
c. Angle of attack indicator
d. g meter
e. q meter (dynamic pressure)
f. Roll rate indicator
g. Inertial altitude indicator
h. Inertial speed indicator
i. Inertial rate-of-climb indicator
j. Stabilizer position indicator
k. Altitude indicator (3 axis ball)

In addition to these indicators, newly developed displays are being tested in current and future flights. These displays include peak altitude prediction displays, ground track error indicators, on-board energy management displays, and moving tape indicators.

2.7 Attitude Indicator

Attitude information is presently displayed to the pilot by means of a three-axis all-attitude indicator similar to the one shown in Figure 2-8. This indicator contains a spherical ball about 3-1/2 inches in diameter with unlimited freedom in the three aircraft axes, and it is servo-driven from an on-board inertial platform. The sphere has a white horizon line with

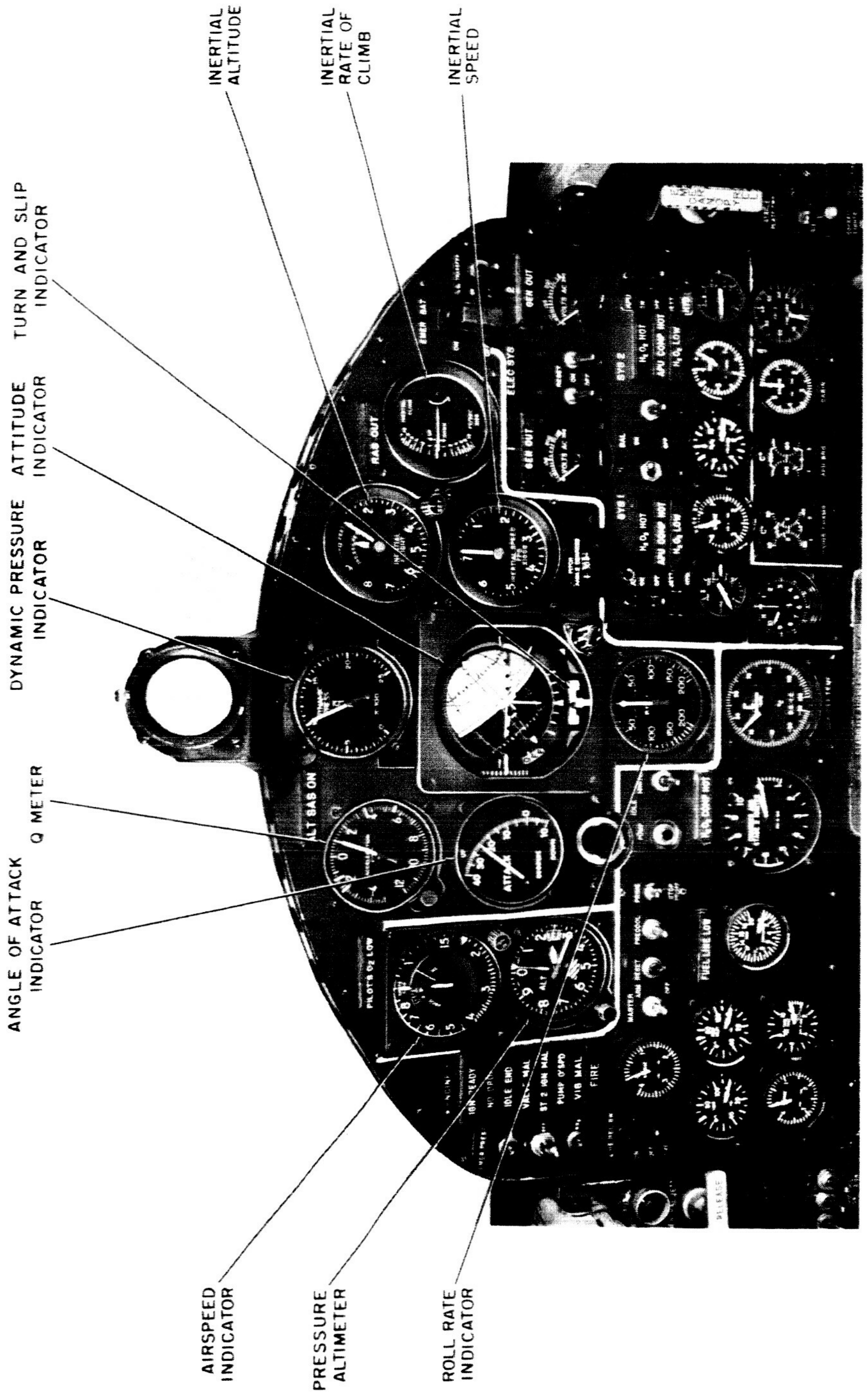

Figure 2-7. Instrument Panel Configuration

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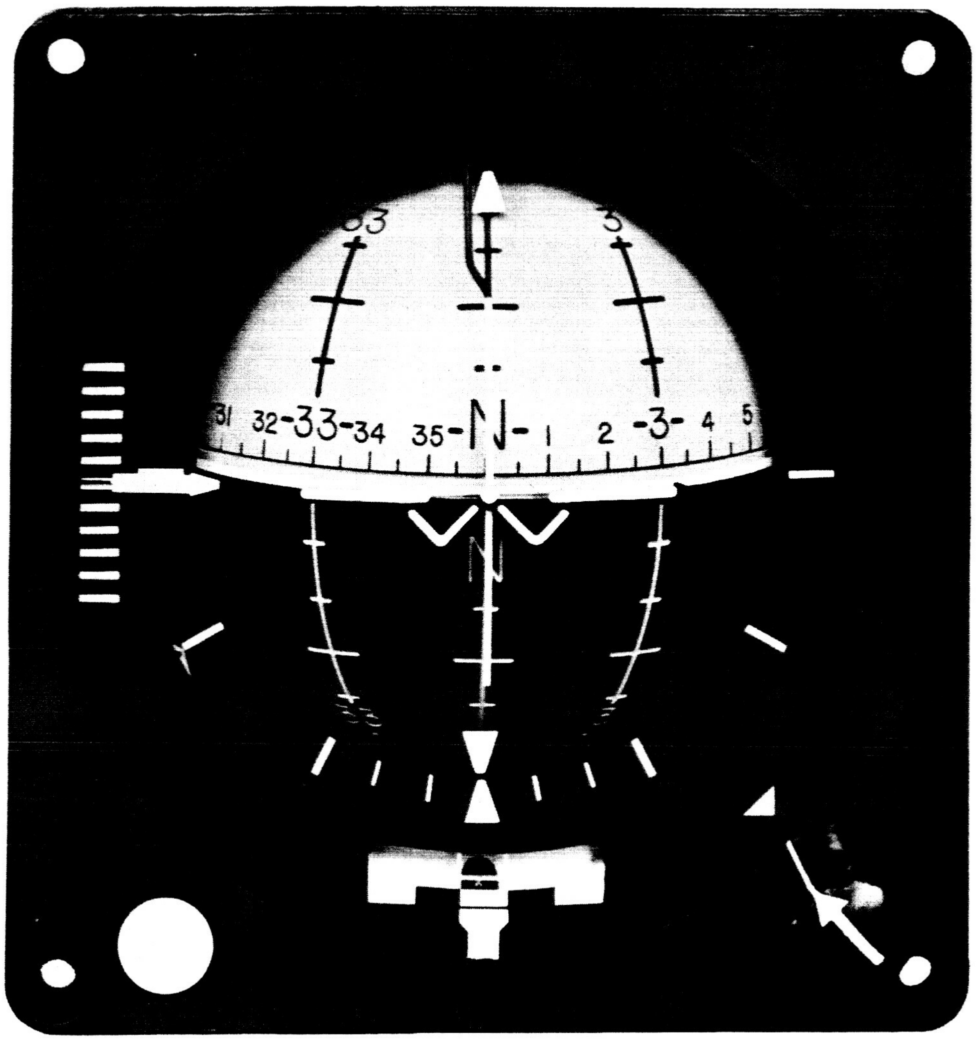

Figure 2-8. All-Attitude Indicator

azimuth markings every 5 degrees. It is colored white above and black below the horizon. Vertical azimuth lines are included at every 30 degrees of azimuth with supplemental pitch markers every 10 degrees along their length. In a special modification for the X-15, additional azimuth markers have been provided on the ±30 degree pitch lines.

Superimposed vertical and horizontal crosspointers are used to indicate angle of attack and sideslip angle. A mode switching arrangement in the X-15 allows the vertical crosspointer to be used for displaying heading error instead of angle of sideslip. Typical sensitivities for these parameters are as follows:

a. Angle of attack: $\pm 5^{\circ}$ F.S.*
b. Angle of sideslip: $\pm 12^{\circ}$ F.S.
c. Heading error: $\pm 12^{\circ}$ F.S.

A vernier pitch indicator is located on the left side of the faceplate. It has a total range of ±5 degrees and displays pitch error from a command pitch attitude which is set in on a counter below the display.

Roll is displayed by a roll pointer which moves with the roll axis of the spherical ball. Readout is provided by reference markers on the faceplate at ±10, ±20, ±30, ±60, and ±90 degrees.

Information is currently being obtained concerning the operating characteristics of this indicator.

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* Measured with respect to preset angle

2.8 Contact Analog Display Description

2.8.1 General

The concept of display integration discussed in this study is known as the Vertical Situation Display System, or simply contact analog. The latter name refers to the method of display used, and it presents important flight parameters in the form of a synthetic picture representing the real-world view from the pilot's position. The picture is generated by a series of computations on input data received from the aircraft sensors and is displayed on the face of a cathode ray tube.

A photograph of an operating contact analog display is shown in Figure 2-9. The basic picture contains a ground plane with textural elements shown in true perspective, an artificial horizon, and a sky with clouds. A flight path can be superimposed on this background giving command flight information. Additional symbols, such as cross, square, and ground position identifier, are provided.

2.8.2 Display Format

The ground texture represents the surface of the earth by a plane containing a pattern of shaded squares. The orientation of the vehicle with respect to the earth is described by roll, pitch, and heading angles and is shown by corresponding motions of the display elements. Vehicle altitude is displayed by variations in the apparent size of the squares which make up the ground texture pattern. The pattern has motion in proportion to the aircraft velocity in the direction opposite the vehicle motion.

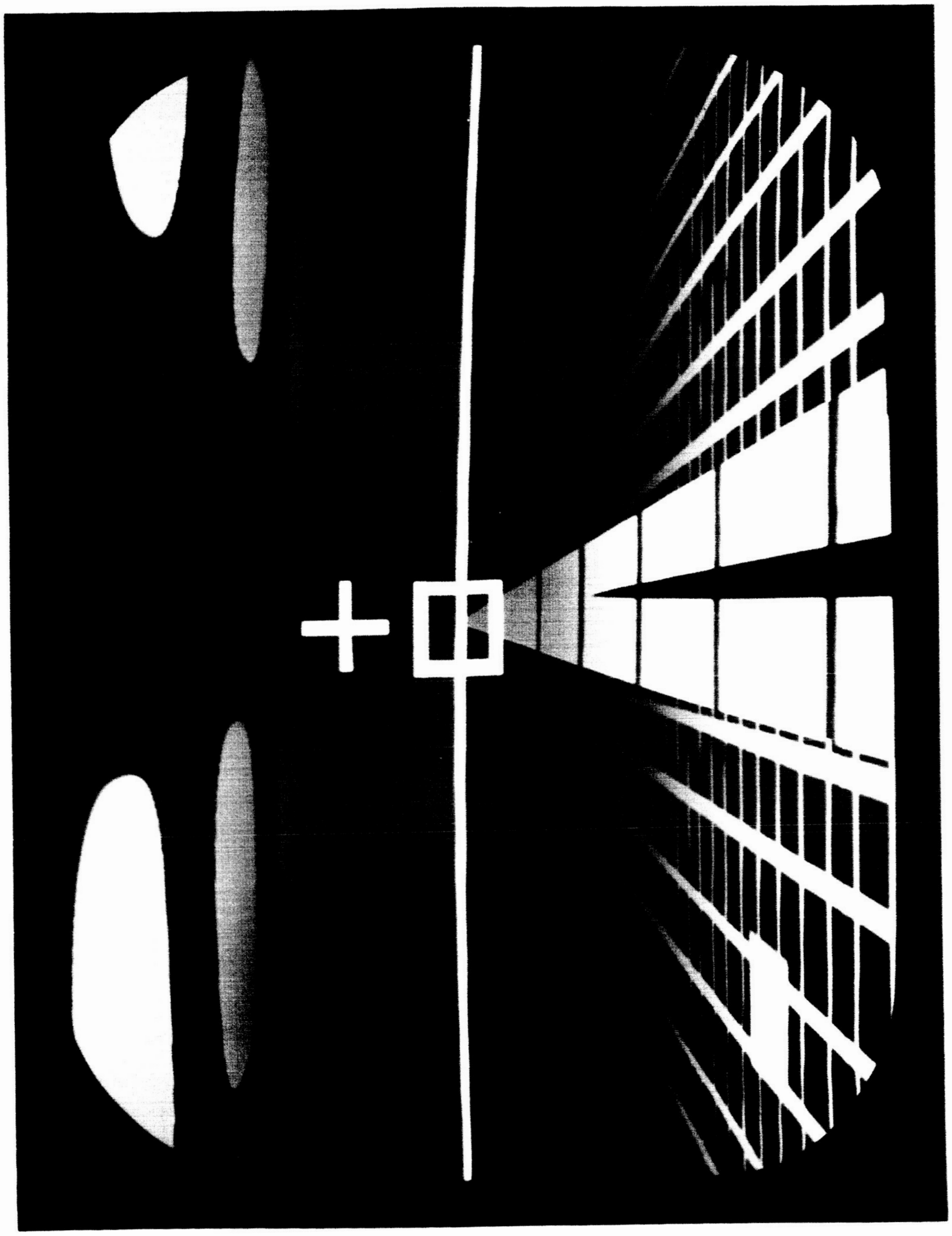

Figure 2-9. Contact Analog Display

The command path contains a centerline and tarstrips which move toward the vehicle. Path orientation is described by roll, pitch, heading error, slope error, altitude error, and lateral offset. A typical system contains several modes of pathway presentation. These include command, navigational and reentry modes. Various path configurations are shown in Figure 2-10.

In the command mode, the pathway is vehicle-stabilized, i.e., fixed to a point beneath the aircraft. During normal flight, the path is approximately 15 feet below the aircraft and vanishes at the center of the screen. Heading errors cause the path tip to bend left or right, and slope errors move the tip up or down. Roll angles cause a corresponding roll motion of the path. A lateral displacement will cause the near-end of the path to move right or left while the tip remains fixed. The primary advantage of this mode is that the path does not disappear from the screen under conditions of large heading and slope errors.

The navigational mode is similar to the command mode except that the path is earth-stabilized. The path does not bend in this mode to indicate a command turn, but merely changes apparent heading. (As a result, excessive heading errors could cause the path to move off the screen.) This mode is used primarily in situations where input information is available in navigational form.

The reentry mode contains two paths which form a "corridor" for displaying upper and lower limits of flight, such as those defined by heating limits, deceleration limits, and minimum entry angles. The corridor has the same degrees of freedom as the navigational pathway.

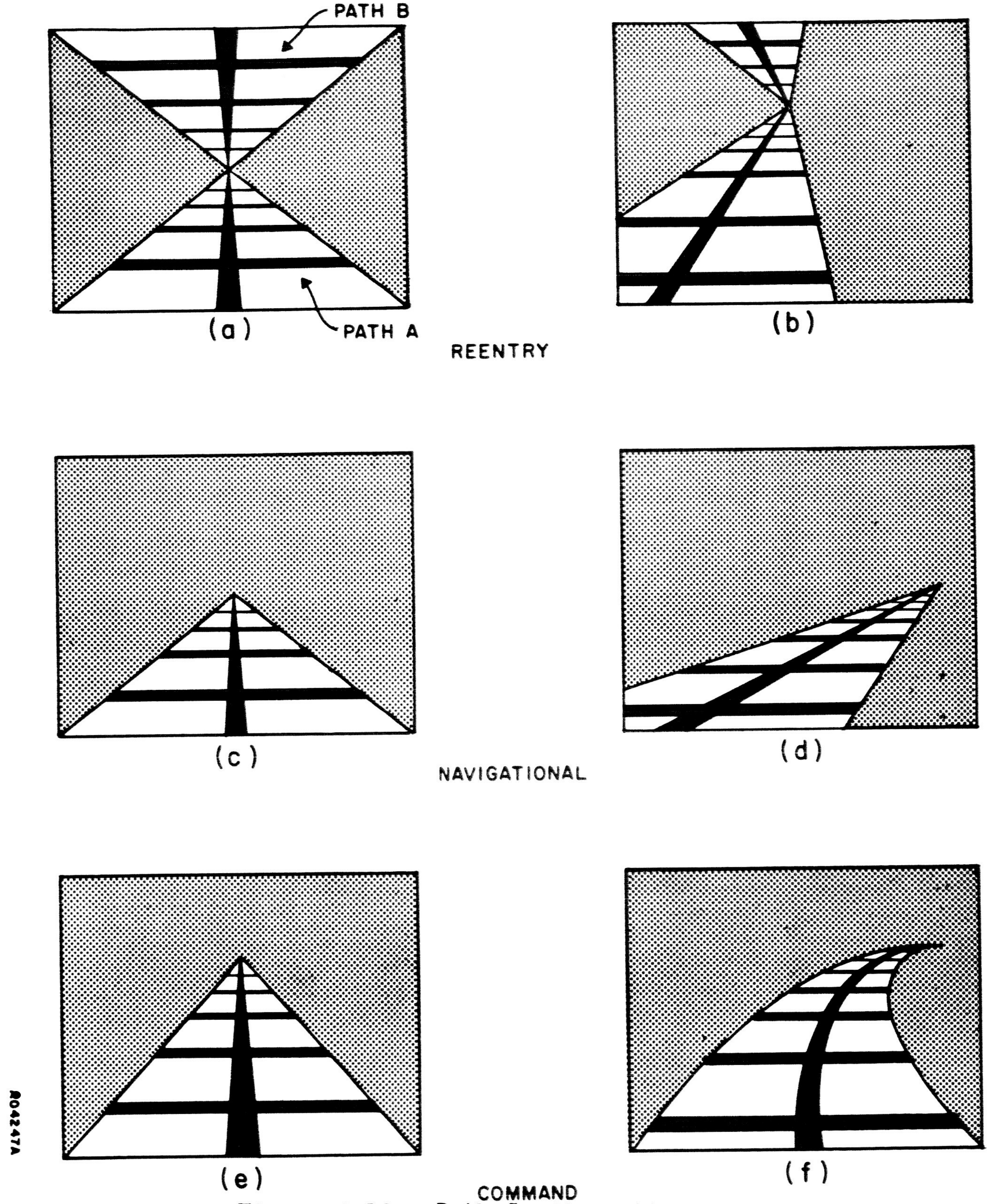

Figure 2-10. Path Configurations

Cross and square symbols are provided for display of variables which have no direct counterpart in a real-world picture. These symbols can be used to display such parameters as angle of attack, angle of sideslip, impact point, and vehicle longitudinal axis.

The ground position identifier effectively illuminates a specific portion of the ground plane and represents selected ground features such as landing areas, obstacles, or landmarks.

2.9 Flight Research Center Display Program

A program for the experimental determination of pilot performance with contact analog equipment is under way at Flight Research Center. The display equipment being used is shown in Figure 2-11. An external television monitor was mounted in a general purpose cockpit simulator having the performance range of the X-15 vehicle with necessary inputs provided by the existing simulation computers.

A list of the areas under investigation in this program is shown in Table 2-4. Data obtained from these or similar experiments will be included in the final report, if schedule considerations permit.

A document pertaining to the use of this equipment with the X-15 flight profile was generated as a part of this study and is included in the following section.

2.10 Preliminary Conclusions on the Use of Contact Analog With X-15 Profile

2.10.1 Pathway Modes

Under conditions of ballistic flight where aerodynamic control is not possible, the command pathway should be used since

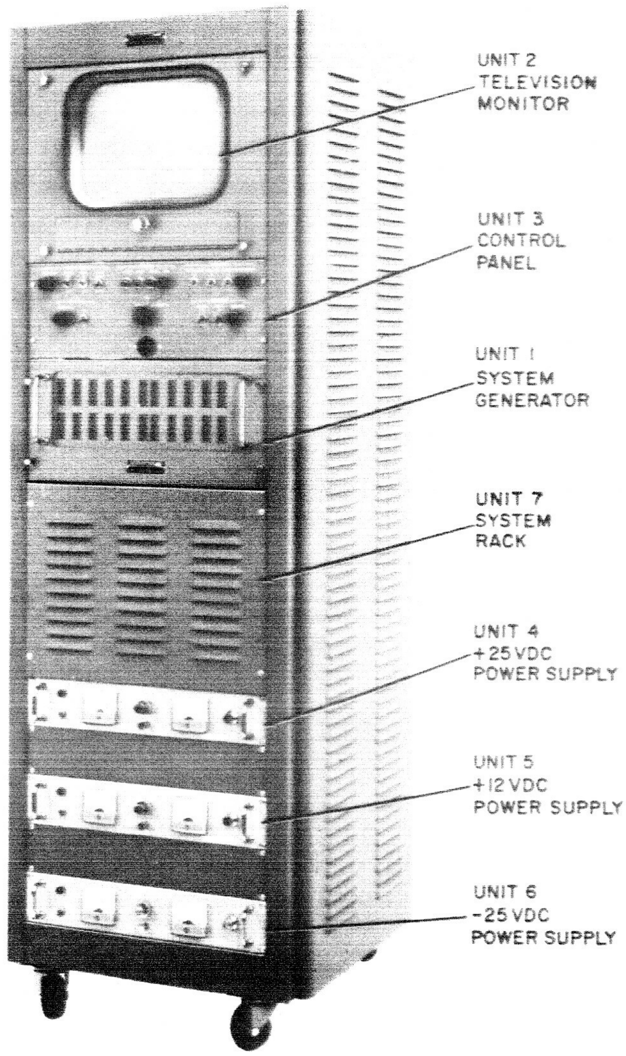

Figure 2-10. Edwards Flight Research Center
Contact Analog System

Table 2-4. Contact Analog Experimental Areas of Study

GROUND PLANE AND HORIZON ONLY	
Ability to:	Discern attitude and attitude rates Assume given attitude (accuracy) Hold given attitude Discern unusual attitudes Discern changes in attitude Discern changes in velocity Discern attitude in absence of horizon
PATHWAY ONLY	
Ability to:	Discern attitude and attitude rates Hold given attitude Estimate and Correct (Altitude Error (Lateral Displacement (Heading Error Estimate velocity Follow fast command inputs
GROUND PLANE PLUS PATHWAY	
Comparison of path modes relative to:	Flight phases Recovery from excessive errors from command inputs Attitude information content
GENERAL	
Ability to follow command inputs:	Uses of cross and square Optimum sensitivity of symbols Information content vs. percent of screen area Other path configurations Quantitative readout Predictive displays

in this mode, it is not possible to "lose" the pathway due to excessive errors in heading, altitude, or lateral displacement. During portions of the flight when vehicle is under aerodynamic control, the navigational or reentry pathways can be used. In all three modes, attitude error information can be derived from the pathway in the absence of the horizon.

The reentry mode is used to indicate reentry corridors defined by maximum heating limits, maximum g limits, minimum reentry angles, etc. In such cases, the width of the corridor may be varied by appropriate scaling of the altitude error inputs $|h_e|_A$ and $|h_e|_B$.

Aircraft velocity or velocity error can be displayed on the pathway tarstrips (VA). The distance-to-path end input can be used to display checkpoints along a given flight. For example, the tip of the path could be programmed to approach the pilot at the same velocity as the tarstrips to indicate an oncoming transition between flight phases, such as burnout, pushover to zero g, and high key. In such cases, the path would decrease in length at a predetermined rate until it disappears at the edge of the screen. At this time, a new path would appear giving command information for the next phase.

2.10.2 Ground Plane and Horizon

The ground plane and horizon provide basic information concerning attitude, (roll, pitch and heading), altitude, and velocity. At large pitch angles, the horizon is not on the screen, and attitude information must be obtained from the pathway. The vehicle velocity inputs (V_N, V_E) can be made proportional to aircraft velocity, or remain constant.

Altitude scaling should be chosen for greatest sensitivity consistent with dynamic range considerations. If only a portion of the mission is to be simulated, scaling can be chosen so that no scale switching occurs. An example of this might be the boost phase requiring an altitude range from 45,000 to 450,000 feet. Since this is only a 10 to 1 range, one scale with a scale factor of X 450 feet could be used. If the maximum altitude is limited to about 300,000 feet, one range would be sufficient for about 80 percent of the flight from launch to high key point. Using all three altitude scale ranges, altitudes from approximately 500 feet to 500,000 feet can be effectively displayed.

2.10.3 Symbols

2.10.3.1 Cross and Square

Past experience has shown that the square is the preferred symbol for representing the vehicle longitudinal axis. The hollow center permits viewing the tip of the pathway at null, thus, permitting greater accuracy.

The cross used in conjunction with the square represents flow direction (α and β). Heading error and pitch error are displayed with the cross during portions of the flight when these parameters are of prime importance. In this case, the sensitivity of the input signals can be increased to provide the required vernier indications for increased accuracy.

2.10.3.2 Ground Position Identifier

The Ground Position Identifier (GPI) is used to indicate the terminal landing area or any of the emergency landing areas with suitable mode switching. It could also represent high or low key checkpoints, but some visual extrapolation would be necessary since the GPI is in ground coordinates.

If landing maneuvers are to be conducted, the GPI can be utilized in conjunction with the path cutoff input. The path is adjusted to terminate at the GPI to represent a given glide slope. To conduct the maneuver involves programming the cross inputs to represent aircraft velocity vector and maintaining the cross within the GPI during the approach.

3. PROGRAM FOR REMAINDER OF STUDY

Efforts for the final period of this program will be directed toward generation of an integrated cockpit display design based on further extensions of the preliminary concepts established to date. Once the display format has been determined, emphasis will be placed on design requirements of flyable model displays as well as extension of the capabilities of present simulator models. Such designs will include budgetary estimates, where possible.

Human factors considerations will play a large part in selection of display technique and content. Attempts will be made to obtain experimental data to support this area of the study. This work will be conducted with available displays and simulation facilities. Application of closed circuit television to vehicle control using video mixing techniques will be considered.

APPENDICES

APPENDIX A

A. X-15 VEHICLE CHARACTERISTICS

A.1 General

Length:	50 feet
Wingspan:	22 feet (wing sweep 25°)
Height (with lower vertical):	13 feet
Power Plant:	YLR-99 engine
Maximum Thrust:	57,000 pounds
Minimum Thrust:	28,000 pounds
Fuel and Oxidizer:	Anhydrous ammonia - liquid oxygen
Weight:	
Launch:	32,800 pounds
Burnout:	15,000 pounds
Payload (for experimental equipment):	2000 pounds
Electrical System:	115 vac 400 cps
	26 vac 400 cps
	28 vdc

A.2 Performance Characteristics

	DESIGN LIMITS	ATTAINED TO DATE
Altitude	250,000 feet	351,000 feet
Velocity	6,600 fps	6020 fps
Maximum Skin Temperature	1200°F	1150°F
Maximum Dynamic Pressure	2500 psf	2000 psf

APPENDIX B

B. INERTIAL PLATFORM INTERFACE DATA

FUNCTION	TYPE OUTPUT	SCALING
Heading	Synchro	1° per 1° shaft rotation
Pitch	Synchro	1° per 1° shaft rotation
Roll	Synchro	1° per 1° shaft rotation
Altitude	Synchro	500K feet per shaft rotation
N-S Velocity	Potentiometer	7000 fps per 2K ohms
E-W Velocity	Potentiometer	5000 fps per 2K ohms
Vertical Velocity	Potentiometer	5000 fps per 2K ohms
Total Velocity	-------------	Amplifier in indicator sums V_{NS}^2, V_{EW}^2, and V_H^2 and extracts square root through potentiometers
N-S Distance	Synchro	720 nautical miles/shaft rev.
E-W Distance	Synchro	240 nautical miles/shaft rev.

APPENDIX C

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e. X-15 OPERATIONS - ELECTRONICS AND THE PILOT: Neil Armstrong, Astronautics, May 1960

f. OPERATIONAL FLIGHT TEST EXPERIENCE WITH THE X-15 AIRPLANE: Perry V. Row, Jack Fischel, AIAA Space Flight Testing Conference, Cocoa Beach Florida, March 18-20 1963, Paper 63075

g. DESIGN AND OPERATION OF THE X-15 HYPERSONIC AIRPLANE: George R. Mellinger, North American Aviation, Inc., NA-60-1070

APPENDIX D

D. PROJECT MANAGEMENT

D.1 General

The contract was received on May 16, 1963. Preliminary tasks included:

a. Review of contract for technical content

b. Initiation of literature survey

c. Liaison meetings with Technical Program Director

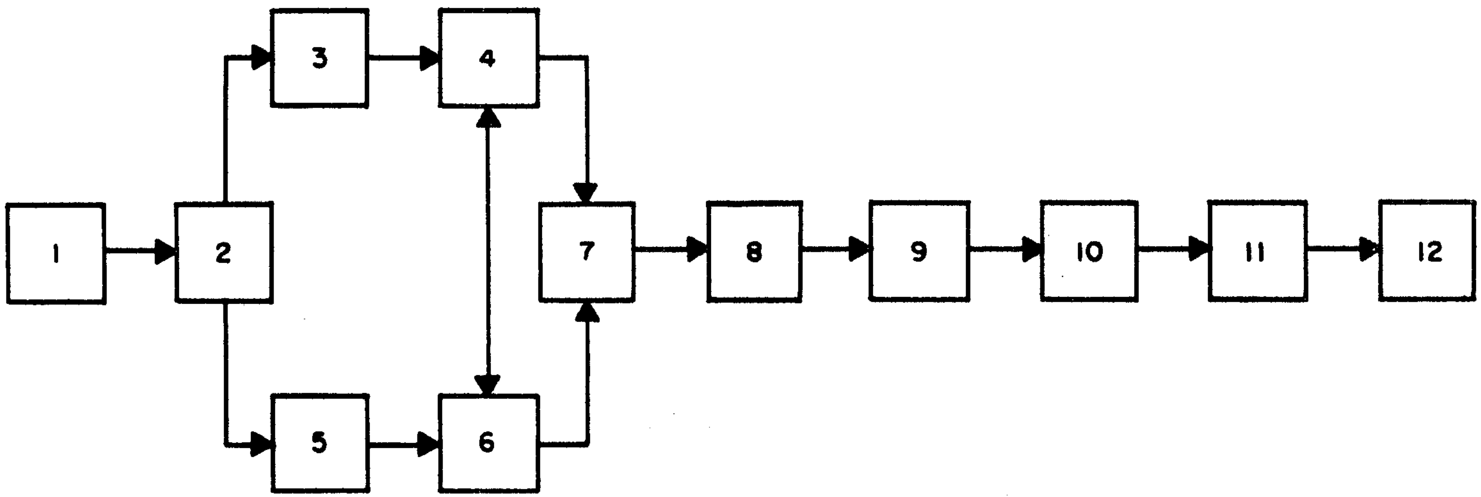
An outline of the study program appears in Figure D-1. This reflects the revised objectives discussed in paragraph D.5.1. Work has progressed up to and including the display integration methods phase the results of which have been incorporated in Part 2 of this report.

Figure D-2 shows the cumulative engineering manpower for the entire program, the actual level to date, and the projected manpower for the next three months. An increased manpower effort is planned for the second half of the program.

Also shown in Figure D-2 is a graph of expenditure to date versus total project funds. This indicates that 32 percent of project funds have been spent as of the end of the reporting period. This is primarily the result of the lower level of manpower loading for the first study period. Documentation expenses are not reflected in this figure.

D.2 Schedule

The schedule for the six-month study period appears in Figure D-3. The first phase of the program involving program



1. X-15 VEHICLE AND PROGRAM FAMILIARIZATION
2. MISSION PROFILE ANALYSIS
3. FLIGHT PARAMETER AND SENSOR STUDY
4. ANALYSIS OF PRESENT DISPLAY METHODS
5. PILOT TASK ANALYSIS
6. PILOT TASK-DISPLAY PARAMETER MATRIX
7. STUDY OF DISPLAY INTEGRATION METHODS
8. RECOMMENDED DISPLAY CONTENT AND FORMAT
9. TECHNIOUES OF MECHANIZATION
10. SIZE, ACCURACY, RELIABILITY OF SYSTEM
11. RECOMMENDATIONS FOR FOLLOW-ON PROGRAM
12. FINAL REPORT

Figure D-1. Study Outline

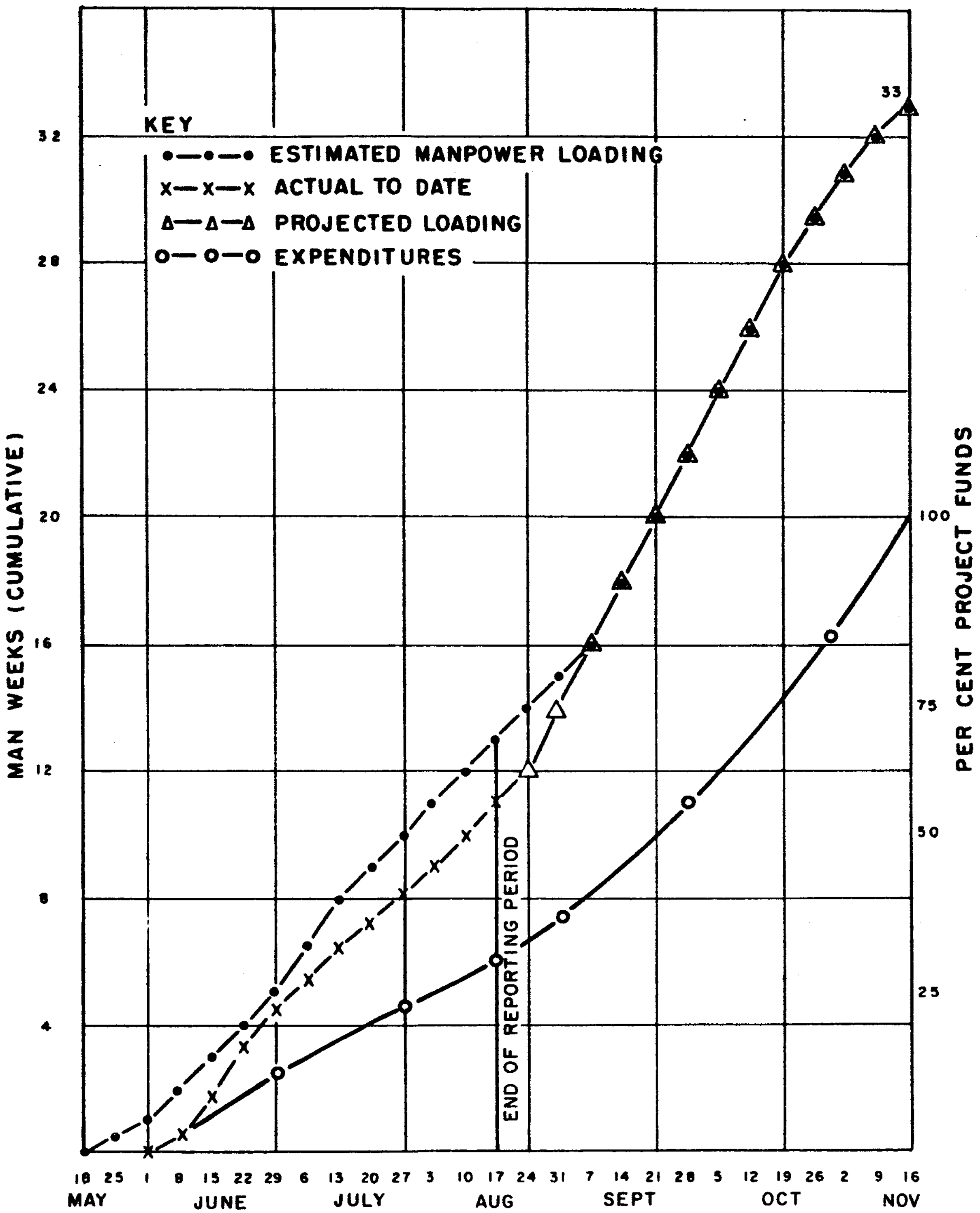


Figure D-2. Cumulative Manpower and Expenditures

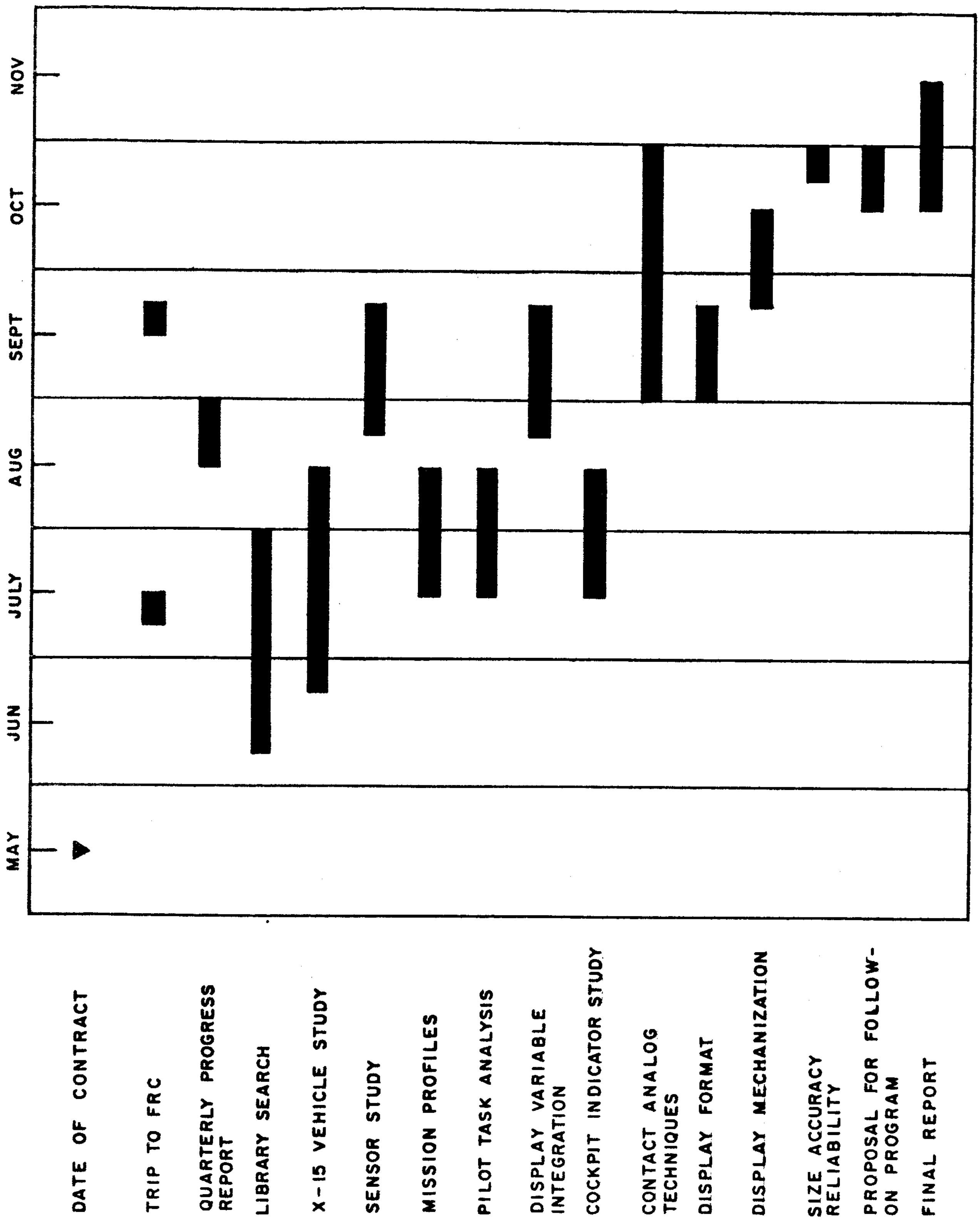


Figure D-3. Project Schedule

definition and accumulation of data is almost completed. The second half of the program will be concerned with the reduction of this data to a meaningful form and the application of contact analog principles to the development of an integrated cockpit display.

D.3 Contract Revisions

As a result of discussions with the Technical Program Monitor and Technical Director (paragraph D.5.1), a revised contract work statement was drafted and sent to NASA headquarters for review. Upon receipt of written approval, the new work statement will be submitted through the proper channels for incorporation in the contract. This was not accomplished at the time of writing this report.

D.4 Literature Survey

A continuing search for technical literature concerning the X-15 program and related subjects is being conducted for the purpose of obtaining the necessary background information to apply to this study. To data, approximately 100 references have been obtained. Some areas of investigation are listed as follows:

a. Aircraft Instrumentation
b. Attitude Control Methods
c. Cockpit Display Systems
d. Flight Simulation Techniques
e. Human Factors
f. Hypersonic Flight
g. Inertial Navigation
h. Manned Spaceflight
i. Piloted Control of Hypersonic Vehicles
j. Reentry Techniques
k. Research Aircraft

D.5 Communications

D.5.1 Trip to NASA Headquarters

A meeting was held at the offices of the Control and Stabilization Program, Office of Advanced Research and Technology, Headquarters, NASA, on June 21, 1963 to discuss plans and objectives of the study program. Personnel in attendance included Mr. Robert Taylor of NASA and Mssrs. T. Kegelman, G. Conron, P. Williams, and J. Chute of Norden.

The program objectives, as outlined in the initial contract work statement were discussed. These are listed in Table D-1. After reviewing these objectives, Mr. Taylor noted that the most immediate need for a study of this type existed in the X-15 program at the NASA Flight Research Center and Ames Research Center, in their space simulation programs. Presently available contact analog equipment was recently purchased by these centers for experimentation purposes. It was, therefore, decided that the content of the study program would be confined to these areas.

It was determined that technical guidance for both areas would be provided by Roger Windblade, Display and Guidance Section Flight Research Center, Edwards Air Force Base.

D.5.2 Trip to Flight Research Center

During the period July 7-10, 1963, a trip was made by the Project Engineer to the Display and Guidance Section, Flight Research Center, Edwards Air Force Base, California. The trip had the following two main objectives:

a. To finalize program objectives and revise contract work statement.
b. To obtain data on the X-15 research vehicle

Table D-1. Original Objectives of Integrated Display Study

a. Conduct a survey of present cockpit display instruments used, or planned for use in space vehicles, including visits to major space development centers to obtain necessary data

b. Hold discussions with pilots and astronauts concerning the degree of adequacy of presently used display methods to determine areas for improvement

c. Conduct a study of pilot tasks for various phases of typical space missions to determine relative importance of flight parameters for each task. Phases to be considered include: launch, orbit, orbit correction, rendezvous, reentry, and landing

d. Investigate methods of display integration on the outcome of the task parameter study, to include contact analog techniques

e. Generate a final report covering the results of the study and recommendations based on these results. These would include a follow-on program for experimental confirmation of the proposed display configurations, including the construction of display models for simulator tie-in, where available.

Several discussions were held to more closely define program objectives and methods of operation. These resulted in a revised contract work statement indicating the change in content of the study. A paragraph was added to the work statement concerning the experimentation program being conducted by the Display and Guidance Section with recently purchased Norden contact analog equipment. This paragraph stated that certain experiments could be suggested by Norden, using this equipment for the purpose of obtaining data for the study.

A large amount of practical data concerning the X-15 missions and vehicle characteristics were obtained during this visit. This included the following items:

a. Technical data on X-15 vehicles
b. Photographs and drawings of presently used cockpit displays
c. Pilot control data for various missions in the form of Flight Request Sheets
d. Graphs of flight data including velocity, altitude, dynamic pressure, temperature, and mach number for typical flights

Several items of technical data required more time than was available to assemble and were sent at a later date. These included a pilot's flight manual, sensor information, environmental specifications, panel indicator data, time-line charts, and radar flight-plots.

Considerable time was spent in familiarization with the current display evaluation and simulation programs at the Flight Research Center. A complete tour of the simulation facilities was made, including the computer facilities. Simulator operation was observed during actual use by a test pilot. Special attention was given to the behavior of cockpit flight instruments under dynamic conditions.

On July 9, an actual X-15 flight was observed from B-52 take off to X-15 touchdown. The majority of the flight was observed from the ground control station where radar tracking data and pilot communications were available. Visual observations were made during the approach and landing phases of the flight.

A second visit to the Flight Research Center is planned during the final period of the study.

D.5.3 Communication with Ames Research Center

A scheduled trip to visit Norman McFadden, of the Man-Machine Integration Branch, Biotechnology Division, Ames Research Center, was cancelled because Mr. McFadden was not at the Center during the period July 7-10, 1963. In his absence, a telephone conversation was held with John Stewart who described their plans for experimentation with contact analog equipment. These plans called for simulation studies in the areas of supersonic transport landings, lunar landings, and low-level-high speed (terrain avoidance) flight. In addition, it was learned that actual work with the contact analog display equipment was not scheduled to begin for several weeks.

Because of the differences in scheduling and areas of study in the Ames programs, it was decided not to include them in the present study effort. This decision has subsequently been approved by Mr. McFadden and Technical Program Monitor, Mr. Windblade.